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THE OPERATION OF A TWO-CHAMBER PNEUDRAULIC SHOCK ABSORBER

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Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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13. ABSTRACT

For the most common types of two chamber, preumohydraulic shock absorbers for S type landing gear, the author presents the functions permitting the shock absorber's initial charging, motion, and force parameters, which arise during the static and dynamic compression of the landing gear by different methods, to be defined. The shock absorber's operational equations, which are stated in a general form, allow the author to create a generalized program for computer solution of the system of dynamic equations of the motion of a landing gear with different types of one chamber and two chamber (with floating pistons in the plunger or cylinder, in addition to a floating needle) shock absorbers.
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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

THE OPERATION OF A TWO-CHAMBER PNEUDRAULIC SHOCK ABSORBER

N. A. Melik-Zade

(Moscow)

Two-chamber pneudraulic shock absorbers are widely used in the landing gear assembly of modern aircraft. In order to determine the loading of the landing gear with two-chamber shock absorbers during the landing process and motion of the aircraft over the surface irregularities of the unpaved airfield, and also in order to select the design of the compression stroke, parking compression, the initial volumes and pressures of the air chambers, equations, expressing the operation of the shock absorbers under static and dynamic compression are necessary.

In this article equations are given, which make it possible to determine the compression stroke, pressures and force in pneudraulic shock absorbers under static and dynamic compression of the landing gear for different designs. The composed equations in general form for the operation of a shock absorber make it possible to create a general-purpose program for solving systems of dynamic equations of the motion of landing gear with different types of shock absorbers on a computer.

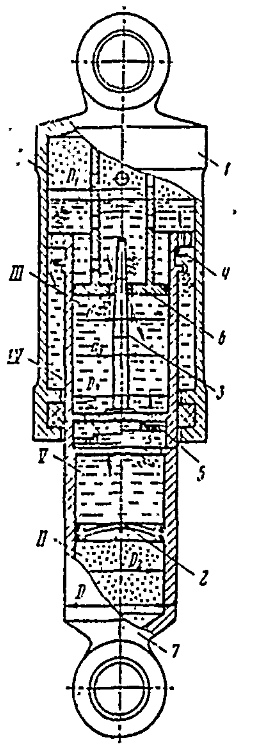

Fig. 1

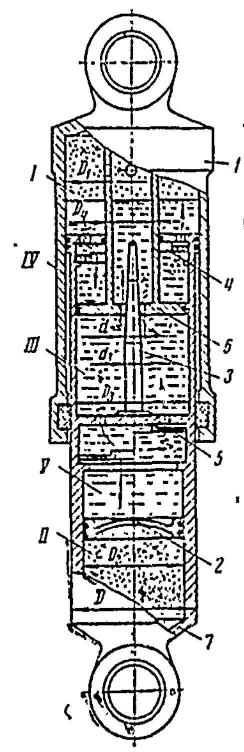

Fig. 2

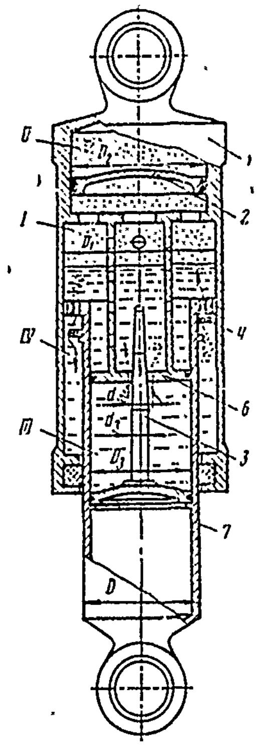

Fig. 3

1. Figures 1-3 shows the basic diagrams of two-chamber pneudraulic shock absorbers which, depending on the pressure of one chamber or another, acting on the floating piston 2, can be subdivided into types, A (Figs. 1, 2) and B (Fig. 3).

A two-chamber shock absorber differs from a single-chamber shock absorber by the presence of two compartmented air chambers, arranged side-by-side and having a different value of initial pressure. Chamber I is an air chamber of a conventional single-chamber shock absorber. Chamber II has, as a rule, an initial pressure, exceeding by several times the initial pressure of chamber I.

During the compression process of shock absorber A at first the chamber is compressed at a low pressure; its characteristics are equivalent to the compression of an air volume at a high

compression ratio. Then, when the pressure of the fluid in chamber III is raised, and becomes sufficient to overcome the initial pressure of chamber II, piston 2 will set in motion, which results in a decrease in the gradient of the pressure buildup.

The hydraulic resistance during the compression of the shock absorber is produced by throttling the return flows of the fluid from chamber III in I and V (in Figs. 1-3 the return flow of the fluid on the forward stroke is shown by solid lines, on the back stroke – by broken lines). The sizes of the throttle openings are selected based on the condition of the absorption of the applied shock at the given g-forces. Besides that, the adequacy of the openings for the return flow of the fluid into chamber V is checked by running over the surface irregularities of the airfield.

By running over rough surface irregularities at a high rate of speed the pneumatic tire on the wheel is sharply compressed and accumulates energy, which is imparted to the moving elements of the landing gear in the form of kinetic energy. Since the energy is quite considerable, the speed of displacement of the piston rod 7 then increases sharply. The resistance to the return flow of the fluid from the chamber III into chamber I, which, at that moment is proportional to the square of the piston rod's speed, becomes so large that the fluid, overflowing into chamber V, is subject to intense compression in chamber II.

Thus, chamber II accumulates the kinetic energy of the moving parts of the landing gear, as a result of which, the peak loads are also reduced. When the mass of the aircraft is displaced upward or if the wheel runs over an obstruction, the loads on the pneumatic tires and on the shock absorber are reduced and piston 2 under the action of compressed air, by extruding fluid into chamber III, returns to the original position.

When running over intermediate and smooth irregularities the two-chamber shock absorber acts as a conventional shock absorber with insignificant variations of the load due to less gradient in the pressure buildup. For the energy absorption of the compressed air in chambers I and II, brake control valves are installed in the shock absorber for the back stroke of the piston rod (valve 4) and piston (valve 5), which overlap all of the openings of a forward stroke on the back stroke, by allowing for the return flow of the fluid using small holes in the valves themselves. The shock absorption of the return valves is very efficient with depression due to large loads, which occur during the motion of the aircraft over a number of highs and lows of the surface.

The difference in shock absorbers A_2 (Fig. 2) and A_1 (Fig. 1) lies in the fact that in A_2 the brake chamber of the back stroke of the piston rod is complete, as confined between diameter D_3 of chamber III and the outside diameter D_4 of plunger 6.

In shock absorber B the compression of the chamber with a low initial pressure occurs up to the point when the pressure in it becomes equal to the initial air pressure in chamber II. With the next stroke of the piston the pressure increases simultaneously in both chambers. Shock absorption on the forward stroke is achieved with the overflowing of the fluid from chamber III into chamber I. Shock absorption on the back stroke is achieved by throttling the return flow of the fluid in valve 4.

In order to reduce the loads when running over rough irregularities either an anti-g valve is installed in shock absorbers B, which increases the fluid flow rate into chamber I upon reaching a specific pressure in chamber III, or an on-off valve is installed, which attenuates shock absorption only during the motion of aircraft on the ground with compressed shock absorbers after the energy of the landing impact is taken up.

The shock absorbers of the A type can also be designed as a version of a shock absorber with a floating needle, if the shaped needle 3 is tightly fitted on a floating piston.

If piston 2 is tightly fitted to the piston rod (shock absorbers A) or in the cylinder (shock absorber B), then one can produce diagrams of single-chamber shock absorbers. Based on this, equations for a single-chamber shock absorber can be obtained from the equations of the operation of a two-chamber shock absorber. To do this in the calculation the value of the initial pressure in chamber II should be intentionally taken as more than the value of the maximum pressure, which can arise during the operation of a single-chamber shock absorber.

2. The work of the external forces during dynamic compression of the shock absorber is spent on air compression (force Q_s), on overcoming friction in the guides (journal boxes) of the piston rod (force Q_τ) and the friction of sealing cups (force Q_μ), on overcoming hydraulic resistance (force Q_v). Absorption on the back stroke is achieved by hindering the fluid in the valve openings, and also by the friction in the journal boxes and sealing cups.

The expression for the total axial force, which compresses the shock absorber, can be written in the following form:

$$Q_\Sigma = Q_s + (Q_\tau + Q_\mu + Q_v)\operatorname{sgn}\dot{S}, \tag{1}$$

where $\dot{S}$ – rate of displacement of the piston rod relative to the cylinder, which is accepted as being positive on the forward stroke, i.e., during the compression of the shock absorber.

The force of friction of sealing cups depends on the value of the coefficient of friction μ, pressure in the shock absorber, the initial stress of the packing and can be approximately expressed by the force of air compression

$$Q_\mu = \mu Q_s. \tag{2}$$

Friction in the guides of the rod depends on the value of the piston rod stroke, coefficient of the friction of the journal boxes, the structural design of the landing gear and the value of the external forces acting on the rod. Force Q_τ can be presented in the form

$$Q_\tau = \varphi_s Q_\Sigma, \tag{3}$$

where φ_s – certain function of the piston rod stroke of the shock absorber, which is determined under the unit axial and transverse forces, applied to the rod for the assigned diagram of the landing gear [1].

Taking into account (2) and (3), equation (1) can be written in the following form

$$Q_\Sigma = Q / (1 - \varphi_s \operatorname{sgn} \dot{S}), \tag{4}$$

where

$$Q = (1 + \mu \operatorname{sgn} \dot{S}) Q_s + Q_v \operatorname{sgn} \dot{S} \tag{5}$$

corresponds to the work of air compression, of flow friction and friction of sealing cups during pure axial compression of the shock absorber ($\varphi_s = 0$). Thus, the shock absorber is loaded in a landing gear with levered-suspension of the wheels (Fig. 4a).

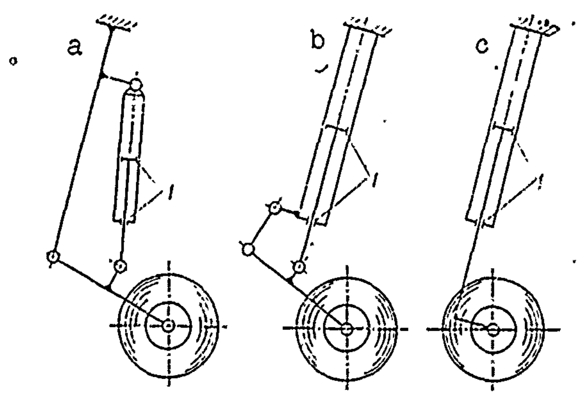

Fig. 4

For a landing gear with a semi-lever suspension (Fig. 4b) or telescopic (Fig. 4c) design the friction in the journal boxes can have great significance. In this case in the expression (4): $\varphi_s < 0$ when $\dot{S} > 0$ and $\varphi_s > 0$ when $\dot{S} < 0$.

With the derivation of the expression for Q_Σ in a general form, which is equally suitable for two-chamber shock absorbers (A and B, and also with the floating needle), as well as for single-chamber shock absorbers, the diagram of shock absorber A_1 can be utilized.

3. Let us examine the air compression with the dynamic stroke of shock absorber not allowing for the work of the fluid. This case corresponds to the work of the forces of air resistance of the shock absorber B, whose diagram of dynamic air compression is wholly determined by the value of the stroke of the piston rod. Besides that, knowledge of the air compression diagram is necessary when determining the initial parameters of the load (p_{01}, V_{01}, p_{02}, V_{02}) of all types of shock absorbers.

The process of dynamic air compression-expansion in the shock absorber will be polytropic, whereupon the polytropic exponents of chamber I (χ_1) and chamber II (χ_2) in general will be different.

During the simultaneous compression of both air chambers the air pressure in chamber I is determined by the expression

$$p_1 = p_{01} / [1 - (S/H_1) + (S_2/H_*)]^{\chi_1}, \tag{6}$$

where $H_1 = V_{01}/k_f F$, $H_* = V_{01}/F_2$, $F = \pi D^2/4$, $F_1 = \pi D_1^2/4$, $F_2 = \pi D_2^2/4$, $k_f = 1$ – for shock absorbers A_1 and B; $k_f = F_1/F$ – for shock absorber A_2; p_{01}, p_1, V_{01} – the initial and current value of the absolute pressure and air volume of chamber I; S, S_2 – piston rod stroke 7 and piston 2; F, F_1, F_2 – areas of compressive air of the rod 7, cylinder 1, piston 2.

The pressure of the compressed air in chamber II

$$p_2 = p_{02} / [1 - (S_2 / H_2)]^{\chi_2}, \tag{7}$$

where $H_2 = V_{02}/F_2$; p_{02}, V_{02} – initial absolute pressure and air volume of chamber II.

Pressures p_1 and p_2 are related by the following equality

$$p_1 = (1 + \mu_2 \operatorname{sgn} \dot{S}_2) p_2, \tag{8}$$

where μ_2 – total coefficient of friction of piston 2 and its packing, $\dot{S}_2$ – rate of displacement of the piston 2; it is taken as positive during compression (decrease in H_2) of chamber II.

When $p_{01} < p_1 \leq p^*_{02} = (1 + \mu_2 \operatorname{sgn} \dot{S}_2)p_{02}$ stroke $S_2 = 0$ and the shock absorber works as a single-chamber.

For the selected parameters of the load the value S_2 is determined from the joint solution of equations (6) and (7) when

$$p_{01} / [1 - (S / H_1) + (S_2 / H_{\bullet})]^{\chi_1} = p_{02}^* / [1 - (S_2 / H_2)]^{\chi_2} . \tag{9}$$

Beginning with $p_1 = p^*_{02}$, the solution of the transcendental equality (9) is made by the method of successive approximation. By a manual calculation the solution can be conveniently arrived at using a graphic method, by assigning a change S_2 with a number of values S. In order to do this in Fig. 5 the right side of the equality (curve 1) is constructed as a function S_2; then, for each selected S_i left side is constructed (9) – curves 2. The points of intersection of curves 2 with curve 1 give the desired S_2 and p_1 as a function S. Having determined the dependence S_2 from S, the diagram of the dynamic compression (curve $\chi > 1$ in Fig. 6) can be constructed.

The main disadvantage in the shock absorbers, shown in Figs. 1-3, is the fact that they cannot work in a horizontal position. During operation in a horizontal position the air and liquid should be completely separated. For this purpose special designs were

developed, whereby it is possible to accept $\chi_1 = \chi_2 = \chi$. Then, from the equality (9), it follows

$$S_2^* = \{p_{01}^{1/\chi} + [(S/H_1) - 1](p_{02}^*)^{1/\chi}\}[(p_{01}^{1/\chi}/H_2) + (p_{02}^*)^{1/\chi}/H_*]^{-1}. \quad (10)$$

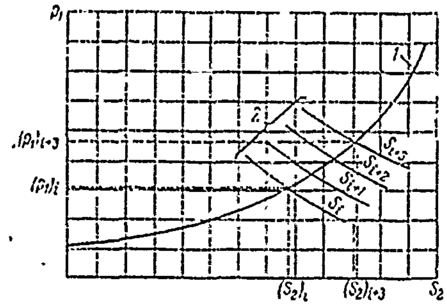

Fig. 5

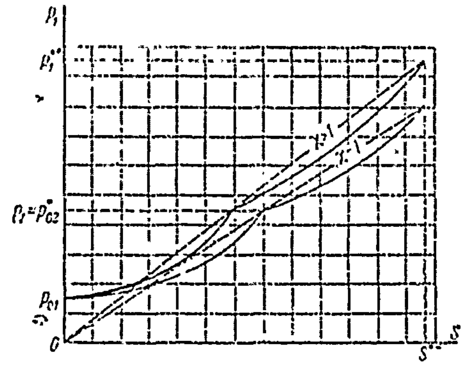

Fig. 6

After the substitution of S_2^* in equation (6), we will obtain

$$p_1^* = p_{01}/[N - (RS/H_1)]^{\chi}, \quad (11)$$

where

$$N = 1 - \Psi[1 - (p_{01}/p_{02}^*)^{1/\chi}]; \quad \Psi = 1/[1 + (H_*/H_2)(p_{01}/p_{02}^*)]^{1/\chi}; \quad R = 1 - \Psi. \quad (12)$$

For a two-chamber shock absorber when $p_1 = p_{02}^*$ and for a single-chamber shock absorber in expressions (12) it is accepted that $\Psi = 0$.

With gradual static compression of the shock absorber the fluid does not become involved in the operation and the process of air compression-expansion is close to isothermal $\chi_1 = \chi_2 = 1$. By utilizing equations (11) and (12), a diagram of static compression (curve $\chi = 1$ in Fig. 6) can be constructed, through which the standing position of compression for the different weights of aircraft are found. The values p_2 and S_2 during static compression are determined from (7) and (10) when $\chi_2 = 1$.

With the correctly selected values of the maximum stroke S**, the standing position of compression and parameters of the load the compression diagram of two-chamber sho·ck absorbers are close to the linear compression diagram of spring compression (dotted lines in Fig. 6). This provides even increases in the loads for the identical changes in the strokes in any dire' ·ion.

The force of air compression Q_s is found from the expression

$$Q_s = (p_1 - p_a)k_f F, \tag{13}$$

where p_1 – is determined by equation (6); p_a – atmospheric pressure.

The difference $(p_1 - p_a)$ determines the excess pressure in chamber I.

At the beginning of the piston rod stroke, $V_1 = V_{01}$ and $Q_s = (p_{01} - p_a)k_f F$; with the subsequent compression, due to the high excess pressures and inaccuracies in the selection χ, it is accepted that

$$Q_s = p_1 k_f F. \tag{14}$$

4. The pressure differentials Δp_i between the chambers, which occur during the displacement of the fluid at a high speed through the throttle openings, are determined from the laws of hydrodynamics

$$\Delta p_i = \xi_i \rho v^2 / 2, \tag{15}$$

where ξ_i – coefficient of hydrodynamic drag, which takes into account friction losses of the fluid; ρ – mass density of the fluid; v_i – velocity of the fluid jet in the i-th opening.

By utilizing the expressions of the flow rate per second, it is possible to express

$$\begin{aligned} \Delta p_1 &= p_3 - p_1 = \xi_1 \rho (F_{III}\dot{S} - F_2\dot{S}_2)^2 / 2f_1^2, \\ \Delta p_4 &= p_1 - p_4 = \xi_4 \rho F_{IV}^2 \dot{S}^2 / 2f_4^2, \\ \Delta p_5 &= p_3 - p_5 = \xi_5 \rho F_2^2 \dot{S}_2^2 / 2f_5^2; \end{aligned} \tag{16}$$

where $f_1 = \pi(d^2 - d_3^2)/4$, $F_{III} = \pi(D_3^2 - d_3^2)/4$; $F_{IV} = \pi(D_1^2 - D^2)/4$ – for Figs. 1 and 3; $F_{IV} = \pi(D_3^2 - D_4^2)/4$ – for Fig. 2; p_1, p_3, p_4, p_5 respectively, – in chambers I, III, IV, V; f_1, f_4, f_5 – total areas of the openings for the return flow of the fluid, respectively, between chambers I and III, I and IV, III and V; F_{III}, F_{IV} – areas of chambers III and IV; designations of the diameters are given in Figs. 1-3.

5. In order to determine force Q_Σ let us express the pressure in the fluid chambers by the air pressure of chamber I, and the corresponding Δp_i

$$p_3 = p_1 + \Delta p_1 \operatorname{sgn} v_1,\ p_4 = p_1 - \Delta p_4 \operatorname{sgn} \dot{S},$$
$$p_5 = p_1 - \Delta p_1 \operatorname{sgn} v_1 - \Delta p_5 \operatorname{sgn} \dot{S}_2, \tag{17}$$

where

$$v_1 = (F_{III}\dot{S} - F_2\dot{S}_2)/f_1.$$

Taking into account expression (17), let us balance the axial force Q

$$Q = 1 + \mu \operatorname{sgn} \dot{S})p_1 k_f F + F_{III}\Delta p_1 \operatorname{sgn} v_1 + F_{IV}\Delta p_4 \operatorname{sgn} \dot{S}. \tag{18}$$

Then, taking into account equations (4) and (16), we will have

$$Q_\Sigma = [(1 + \mu \operatorname{sgn} \dot{S})p_1 k_f F + (\xi_1 \rho F_{III}/2f_1^2)(F_{III}\dot{S} - k_* F_2 \dot{S}_2)^2 \operatorname{sgn} v_1 + \xi_4 \rho F_{IV}^3 \dot{S}_2 \operatorname{sgn} \dot{S}/2f_4^2)(1 - \varphi_* \operatorname{sgn} \dot{S})^{-1}, \tag{19}$$

where $k_* = 1$ for shock absorber A, and $k_* = 0$ – for shock absorber B, $f_1 = f_1(S)$ – in the case of a fixed needle relative to the stroke; $f_1 = f_1(S - S_2)$ – in the case of a floating needle:

when $\dot{S} > 0$: $|\Delta p_4| = p_1$, if $|\Delta p_4| > p_1$; $f_4 = f_4^*$;
when $\dot{S} < 0$: $|\Delta p_4| = p_1$, if $|\Delta p_4| < p_1$; $f_4 = f_4^{**}$;

f_4^*, f_4^{**} – areas of valve 4, on the forward and back stroke, respectively.

With the determined values S and S, the values $\dot{S}_2$ and S_2 are found from the solution of the equations of motion of piston 2 relative to the piston rod (Figs. 1, 2) or the cylinder (Fig. 3).

6. In order to determine S_2 and $\dot{S}_2$, the equation of motion of piston relative to the piston rod of shock absorber A_1 is examined

$$(m_2/F_2)\ddot{S}_2 = p_5 - (1 + \mu_2 \operatorname{sgn} \dot{S}_2)p_2 + \\ + [m_2 + \rho_5(L_0 + S_2) \operatorname{sgn} \ddot{S}]\ddot{S}, \quad (20)$$

where m_2, $\ddot{S}_2$ – mass and acceleration of the piston 2; L_0, ρ_5 – height of column (when $S_2 = 0$) and the mass density of the fluid of chamber V; $\ddot{S}$ – acceleration of the piston rod relative to the cylinder; $\rho_5(L_0 + S_2)F_2$ – mass of the fluid, which acts on piston 2 when $\ddot{S} > 0$ or acts on the base of needle 3 when $\ddot{S} < 0$. Thus, in solving equation (20) $\rho_5 = \rho$ is accepted when $\ddot{S} > 0$ and $\rho_5 = 0$ when $\ddot{S} \leq 0$.

The value $[m_2 + \rho(L_0 + S_2)]\ddot{S}$ for contemporary designs does not exceed 1-2% of p_2 and it can be disregarded. Then, having substituted the value p_5 from (17) in (20) and having divided by m_2/F_2, we will have

$$\ddot{S}_2 = (k_1F_2/m_2)(p_1 - (1 + \mu_2 \operatorname{sgn} \dot{S}_2)p_2 + \\ + k_2\Delta p_1 \operatorname{sgn} v_1 - k_2\Delta p_5 \operatorname{sgn} \dot{S}_2], \quad (21)$$

where $k_1 = k_2 = 1$ when $p_5 > p^*_{02}$ – for shock absorbers A; $k_1 = 1$, $k_2 = 0$ when $p_1 > p^*_{02}$ – for shock absorbers B; $k_1 = k_2 = 0$ when $p_5 \leq p^*_{02}$ (shock absorbers A) or $p_1 \leq p^*_{02}$ – for shock absorber B and for a single-chamber shock absorber with any p_1. $\dot{S}_2$ and S_2 are determined by consecutive integration (21).

During integration in a computer the expressions (21) in conjunction with a system of differential equations of motion of the landing gear, difficulties are encountered when selecting the step of integration Δt. These difficulties are caused by the very low value of mass m_2. The step of integration must be taken sufficiently low, in order to ensure the conditions of convergence and stability of the solution, but at the same time the value should be sufficiently great, in order that one could avoid too great a rounding error. This results, as a rule, in the solution of a system of equations with a variable step, which considerably complicates the program of the computer and increases the required computing time.

If when solving the problem of loading the landing gear, it is not necessary to calculate the mass force, acting on piston 2, then without a specific error it is possible to accept $m_2\ddot{S}_2 = 0$, and from (21), to obtain a quadratic equation relative to S_2: $a\dot{S}_2^2 + b\dot{S}_2 + c = 0$. Whence

$$\dot{S}_2 = (-b - \sqrt{b^2 - 4ac}) / 2a, \qquad (22)$$

where $a = 1 - (\xi_5 f_1^2 / \xi_1 f_5^2) \operatorname{sgn} v_1$, $b = -2\dot{S}F_{III}/F_2$, $c = (b/2)^2 - (2f_1^2 / \xi_1 \rho F_2^2) [(1 + \mu_2 \operatorname{sgn} \dot{S}_2) p_2 - p_1] \operatorname{sgn} v_1$.

The sign before the radical in (22) is determined from the examination of a maximum case where $f_1 = 0$. The displacement S_2 is found by the integration of the expression (22). For shock absorber B the computation of $\dot{S}_2$ is not necessary. S_2 can be obtained from the solution of equality (9) by the iterative method.

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